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INTERACTION STUDIES OF LASER BEAMS INTERSECTING IN AN ACTIVE MEDIUM

(Crossed Beam Laser)

Fourth

Semi-Annual Technical Summary Report

1 August 1967 - 31 January 1968

ONR Contract No. Nonr-5034(00)
Project Code No. 4730
ARPA Order No. 306

Prepared for

Office of Naval Research
Department of Navy
Washington 25, D. C.

Prepared by

Research and Development Center
General Electric Company
Schenectady, N. Y. 12301

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Program Manager

Dr. J.C. Almasi

Principal Contributor

D.K. Duston

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Heavy Military Electronics Department
General Electric Company
Syracuse, New York

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Section I

SUMMARY

The "frequency pulling" effect of the probe laser due to undesired signal injection from the Q-switched perturbing laser was eliminated by 1) placing an isolator in the optical path of the probe laser beam, 2) changing the beam splitter which combines the probe and perturbing beams from a 50% - 50% to a 92% - 8% beam splitter, and 3) increasing the reflectivity of the probe laser output mirror by 10%.

The probe laser had to be modified to increase the output energy to overcome the additional losses introduced into the system. The Q-switched perturbing laser was changed from an oscillator to an oscillator-amplifier combination to obtain sufficient energy output with reliable operation. This amplifier has a 5/8"D x 20"L Nd-doped glass rod manufactured by Owens-Illinois Company. The output energy from the oscillator-amplifier type of perturbing laser exceeds 5 joules, and the pulse width is 40 nanoseconds.

Interaction amplifier experiments with a liquid nitrogen cooled 2% Nd-doped glass laser rod were initiated. A difficulty arose in that the light scattered from the perturbing laser beam overexposed the streak photographs.

A method of calibrating the streak photographs was developed. An eight step density transmission wedge (21 dB) can be photographed on one side of the streak photograph, and the wedge exposure as well as the spectral streaks can be measured with the densitometer.

By using an electron microscope photographic technique, a study revealed that AOLux 0835 Nd-doped glass is a single phase material.

Section II

WORK PERFORMED

A. INTERACTION AMPLIFIER EXPERIMENT

1. Probe Beam

In order to clearly observe the expected changes in gain on the streak photographs of the probe it was considered necessary to eliminate "frequency pulling"[(1)] of the probe beam. This frequency pulling can be eliminated by reducing the amount of perturbing beam power that is injected into the probe laser Fabry-Perot cavity. Approximate calculations indicated that the frequency pulling due to injection locking can be eliminated if the perturbing beam entering the probe laser cavity can be reduced by a factor of 1000. This can be accomplished by: 1) placing an isolator in the optical path of the probe laser beam, 2) changing the beam splitter which combines the probe and perturbing beams from a 50% - 50% to a 92% - 8% beam splitter, and 3) increasing the reflectivity of the probe laser output mirror by 10%.

The Fabry-Perot cavity of the normal pulse probe laser was modified to increase the output energy of the laser. Increased output was required because of 1) a change in the beam splitter which couples the energy into the interaction amplifier, and 2) the optical losses introduced by an optical isolator in the path of the probe beam. The double sapphire-etalon output mirror was replaced with a 50% reflectivity 10% meter radius dielectric mirror and a single sapphire etalon in the cavity. With the single etalon the desired line spectra was produced. However the etalon had to be aligned with the mirrors to generate sufficient output energy.

A low-level CW 1.06 micron source was used to measure the Verdet constant of Schott SF-6 glass. It was found to be 0.027 minutes per ampere turn at 1.06

(1)Third Semi-Annual Technical Summary Report, pp. 6-9, 1 February 1967 - 31 July 1967

microns; this was a factor of three lower than the value supplied by the manufacturer. During these measurements it was observed that the heat from the magnet which propagated to the rod in a time period of the order of 2 seconds, caused serious degradation of the optical rejection of the isolator. It was necessary to design and fabricate a new magnet which would 1) have a flowing water shield between the magnet and the glass rod, 2) provide a 15% excess magnetic field for margin, and 3) have the proper resistance to operate at 250 volts DC, since the standard 250 VDC laboratory supply was the only source available to deliver 25 kilowatts of DC power.

This isolator was built and is shown in Fig. 1. Although designed for the 15% excess field, the margin was not needed. With uncollimated 1.06 micron light the rejection ratio was found to be 88:1. The ratio may be somewhat higher for collimated light. The magnetic field uniformity is better than 1% across the 0.33 inch diameter the probe beam occupies.

After making the changes described above in the probe laser, the experiments showed that the frequency pulling effects were eliminated. The SFS-6 Schott glass, which was ordered because of a larger Verdet constant than the SF-6 glass, had such a long delivery time that the order was cancelled.

It was decided to check the probe beam for mode locking phenomena after it was reported that it could exist in normal pulse lasers.[(2)] The presence of fluctuations in intensity on the order of 0.1 - 10 nanoseconds might lead to a misinterpretation of data. A check of the probe laser output on the 50 nanosecond scale of the streak camera showed no mode locking. Several streak photographs of the probe laser spectrum are shown in Fig. 2. Calculations were presented later[(3)] which substantiated that a laser operating with the conditions of the probe laser would not be mode locked.

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(2)P.M. Rentzepis and M.A. Duquay, Appl. Phys Letters, 11, p. 218, (1967)
(3)H. Statz, Bull. Am. Phys Soc., Paper No. AA2, p. 163, Feb. 1968

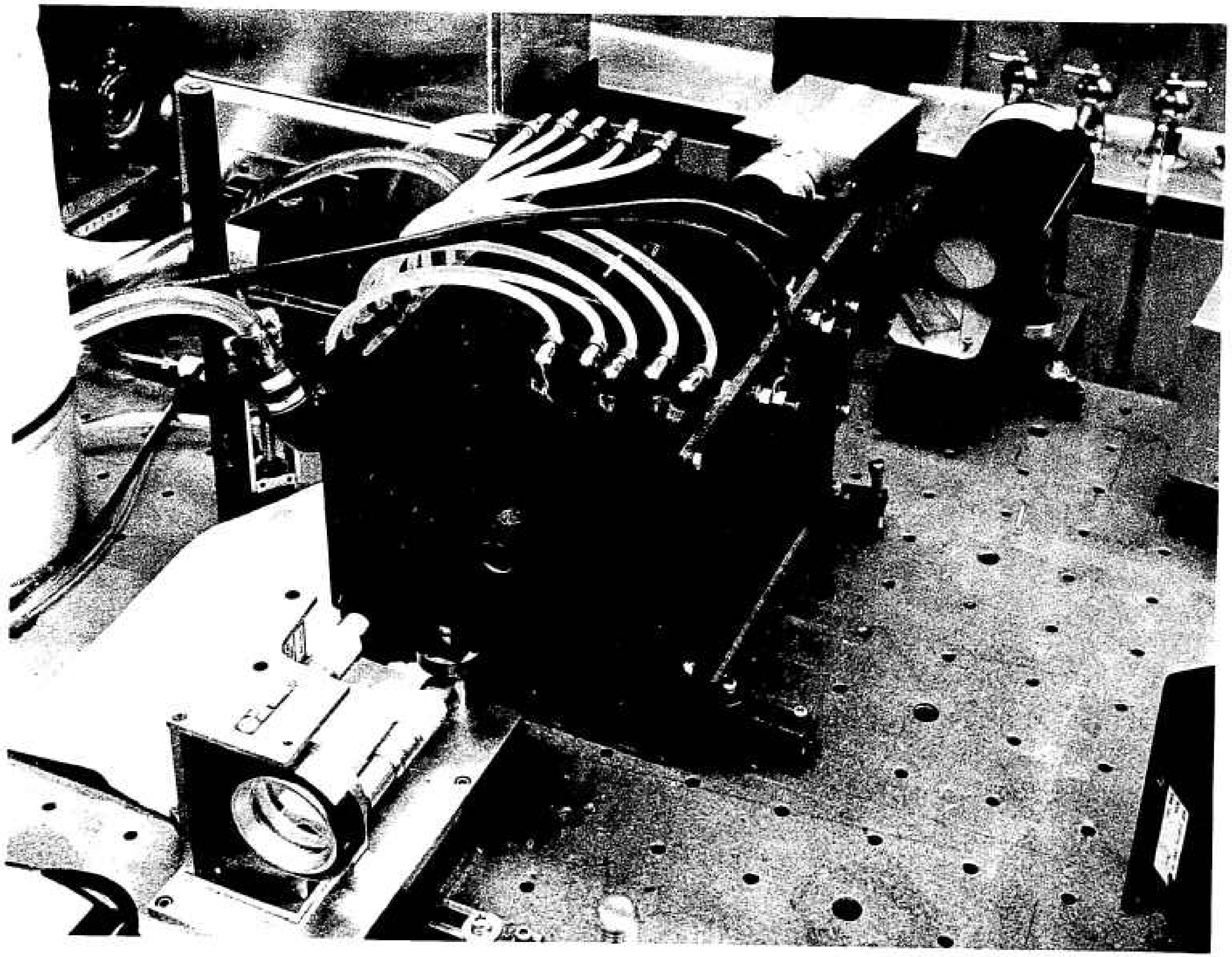


Figure 1. Photograph of Isolator

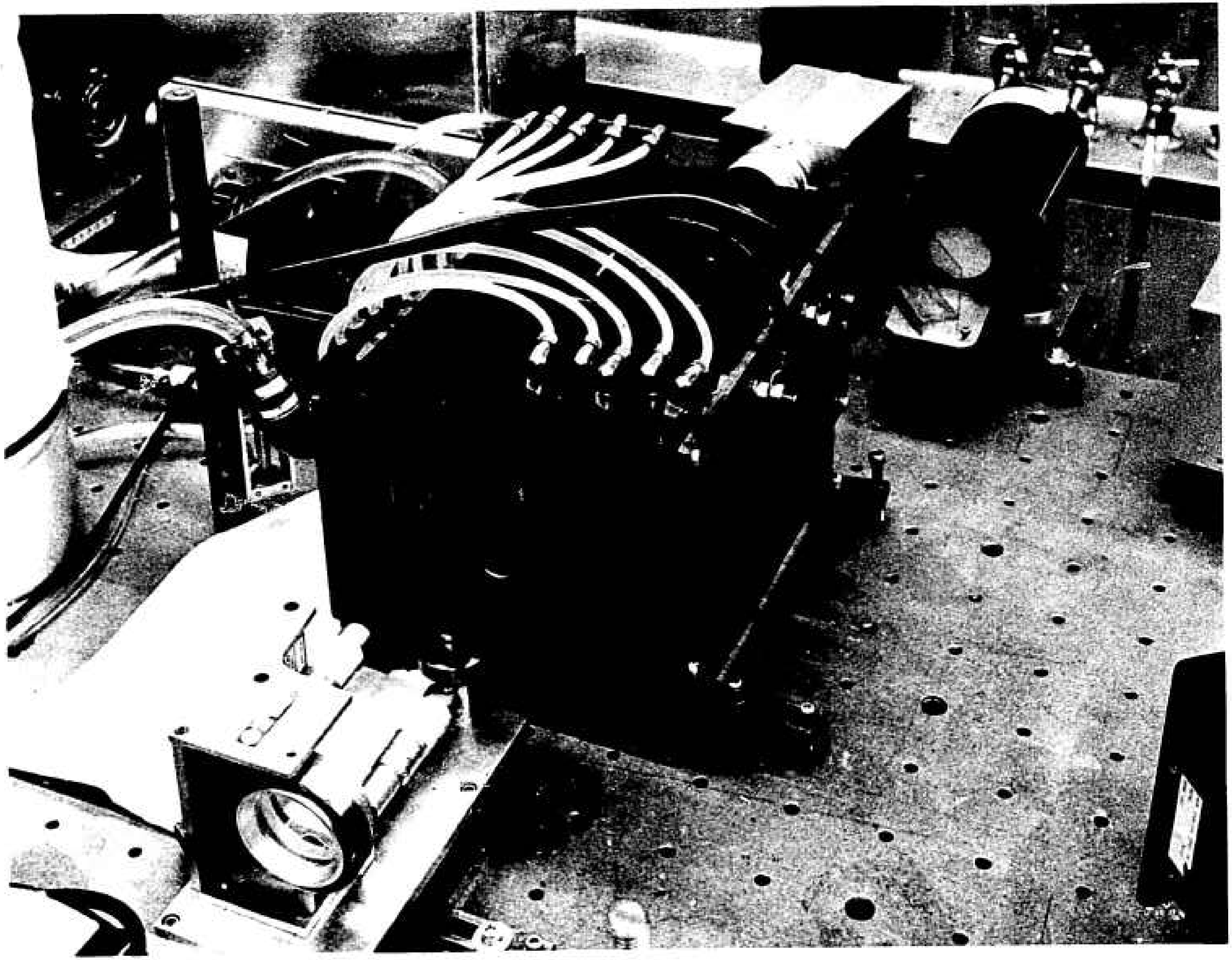


Figure 1. Photograph of Isolator

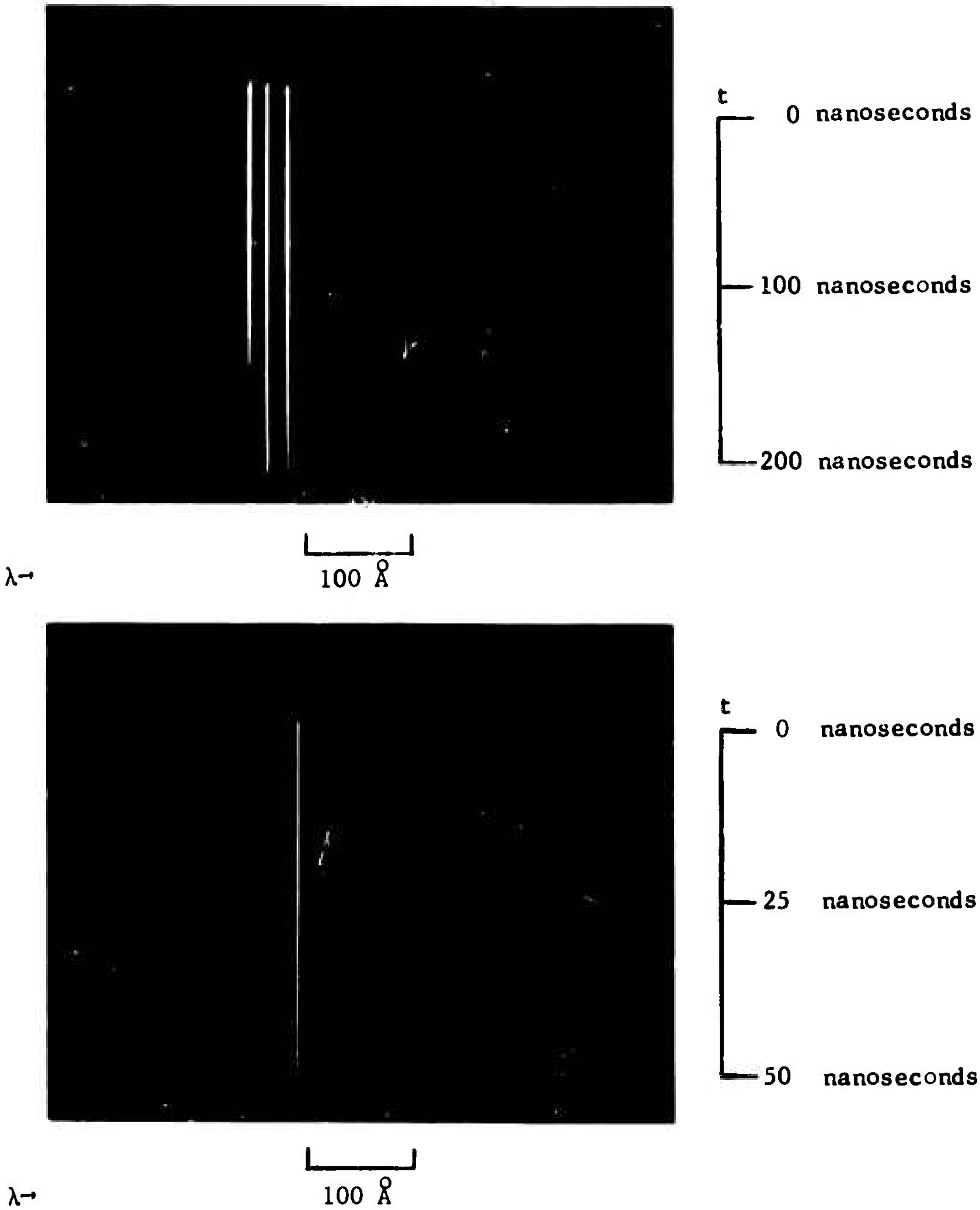


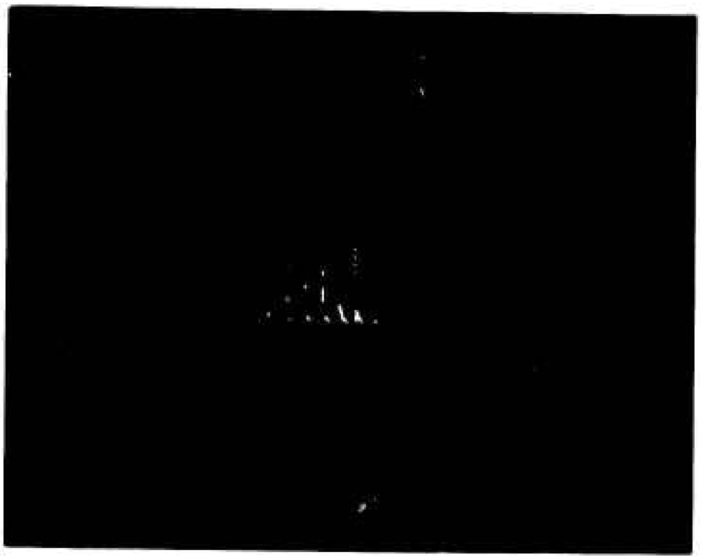
Figure 2. Streak Photographs of Probe Laser

2. High Power Q-Switched Perturbing Laser

Whereas the high power Q-switched oscillator using an American Optical low platinum Nd-doped glass rod delivered 5 joules output during initial tests, subsequently the energy output continually degraded. A close check of the glass rod revealed that bubbles had formed internally. These bubbles were apparently adding significant loss due to scattering and/or mode mixing. The AO rod was replaced by an Owens-Illinois Co. rod with 10^{o} ends, 300 microsecond fluorescent lifetime and 3 wt percent Nd doping. It withstood a peak internal power of 1.8 gigawatts per square centimeter.

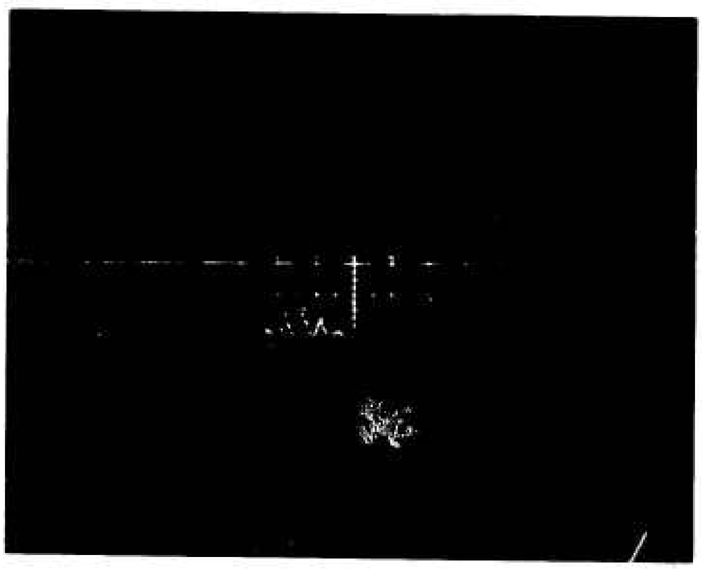
There were several problems with the high power Q-switched perturbing laser using the Owens-Illinois glass rod. The rod had a higher gain, and it was necessary to increase the saturable dye concentration to prevent the rod from normal pulse lasing. Both of the Eastman Kodak saturable absorber dyes were tried. They both would irreversibly bleach in three to six pulses of the laser and hence became useless. The second problem was that the special laser polarizer on the Kerr cell was damaged by the high power. A special polarizing pellicle from the National Photocolor Corp. was purchased and tried. However this polarizer had only a 3:1 rejection ratio at 1.06 microns and seriously limited the hold-off ability of the Kerr cell. Extensive use of this pellicle produced no visible damage to it. The best output pulses from the high power Q-switched oscillator had a peak power of 400 megawatts with a temporal behavior typically illustrated by the two scope photographs in Fig. 3. With the optimum dye concentration this oscillator produced an output of one joule in 50 nanoseconds with a train of 6 or 7 spikes. A calculation showed that a spike could not produce an observable change in the gain of the interaction amplifier. Additionally, this strongly mode-locked Q-switched laser was lasing over a 50 Å spectral width which is much wider than the presumed 20 Å homogeneous linewidth of Nd ions in glass at room temperature.

360 megawatts full scale



20 nanoseconds
per division

360 megawatts full scale



20 nanoseconds
per division

Figure 3. Scope Photographs of Mode Locked
Q-Switched Perturbing Laser

It was decided that this high power Q-switched oscillator could not be used for the perturbing beam. A new configuration was set up which combined a) the low power Q-switched oscillator earlier used in this program with b) the present high power Q-switched oscillator converted into a single pass amplifier. The entire layout with this oscillator-amplifier perturbing laser is shown schematically in Fig. 4. A photograph of the same layout is shown in Fig. 5. Experiments were performed on this combination with and without dye in the oscillator Fabry-Perot cavity simultaneously with and without dye between the oscillator and amplifier to act as a bleaching isolator. It was found that the isolator dye did not increase the maximum Q-switch energy out of the oscillator-amplifier combination. It was also found that the removal of the dye in the low power Q-switch oscillator increased the output energy and increased the system repeatability. The output dielectric mirror was replaced with a double etalon to force the Q-switched perturbing beam to oscillate at a single frequency. Scope and streak camera photographs of a typical output pulse of the oscillator-amplifier configuration are shown in Fig. 6. The output energy in this pulse exceeds 5.0 joules, and the pulse width is 40 nanoseconds. This output is achieved with input energies of 5.1 kilojoules to the oscillator and 7.0 kilojoules to the amplifier.

3. Liquid Nitrogen Cooled Amplifier Experiment

The pump cavity of the liquid nitrogen cooled interaction laser, whose design was previously discussed,[(4)] was assembled with a 1/2" x 6:, 2% Nd-doped glass laser rod. With a 5 kilojoules, 600 microsecond pulse on the pump lamp, the amplifier had a 6 dB single pass small signal peak gain. The entire pump cavity performed satisfactorily over rod temperatures from 87°K to 323°K. A bolometer bridge and amplifier was set up to record the rod temperature on

(4)Second Semi-Annual Technical Summary Report, pp. 10-12, 1 August 1966 - 31 January 1967

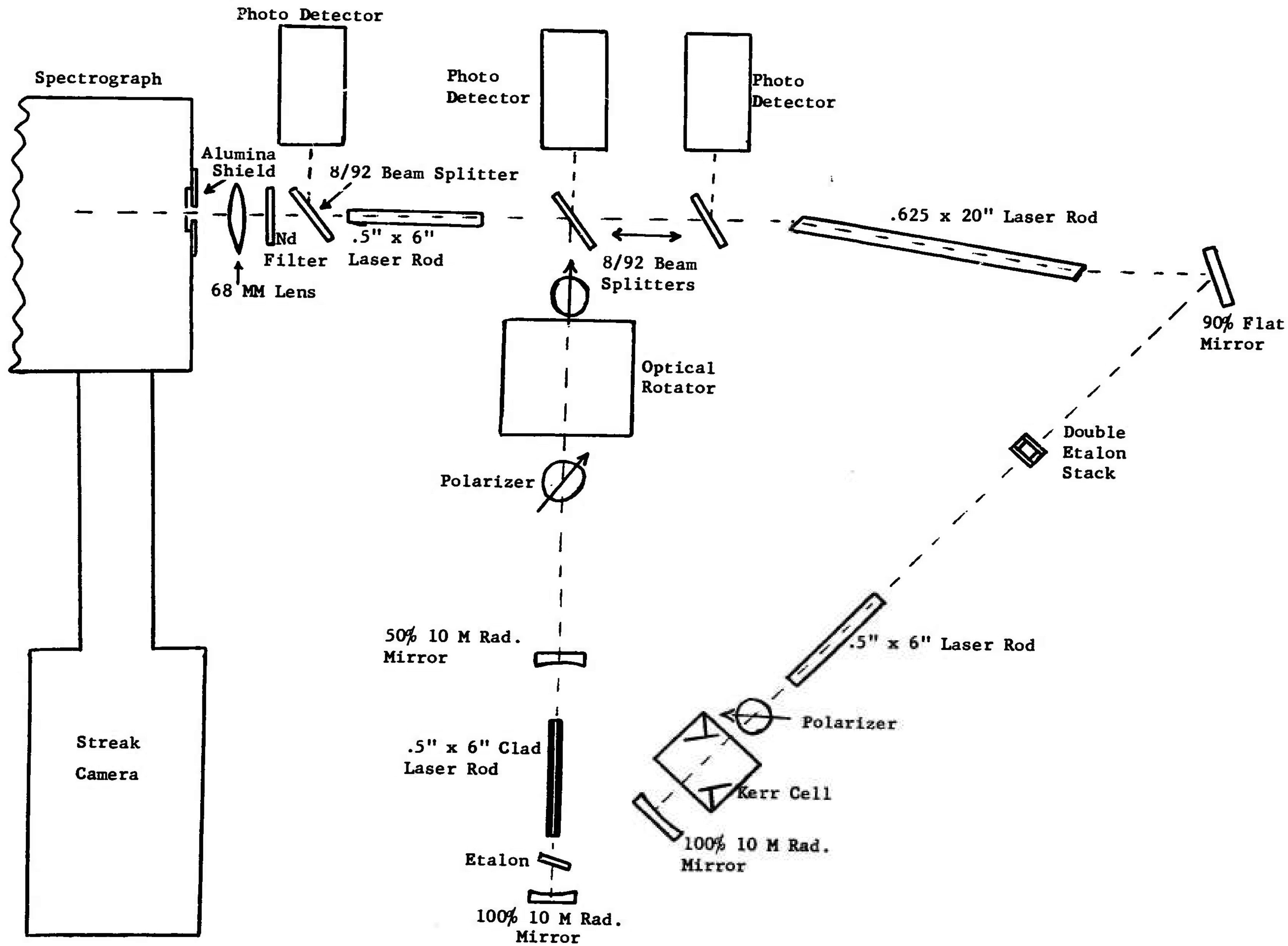


Figure 4. Optical Schematic of Present Layout

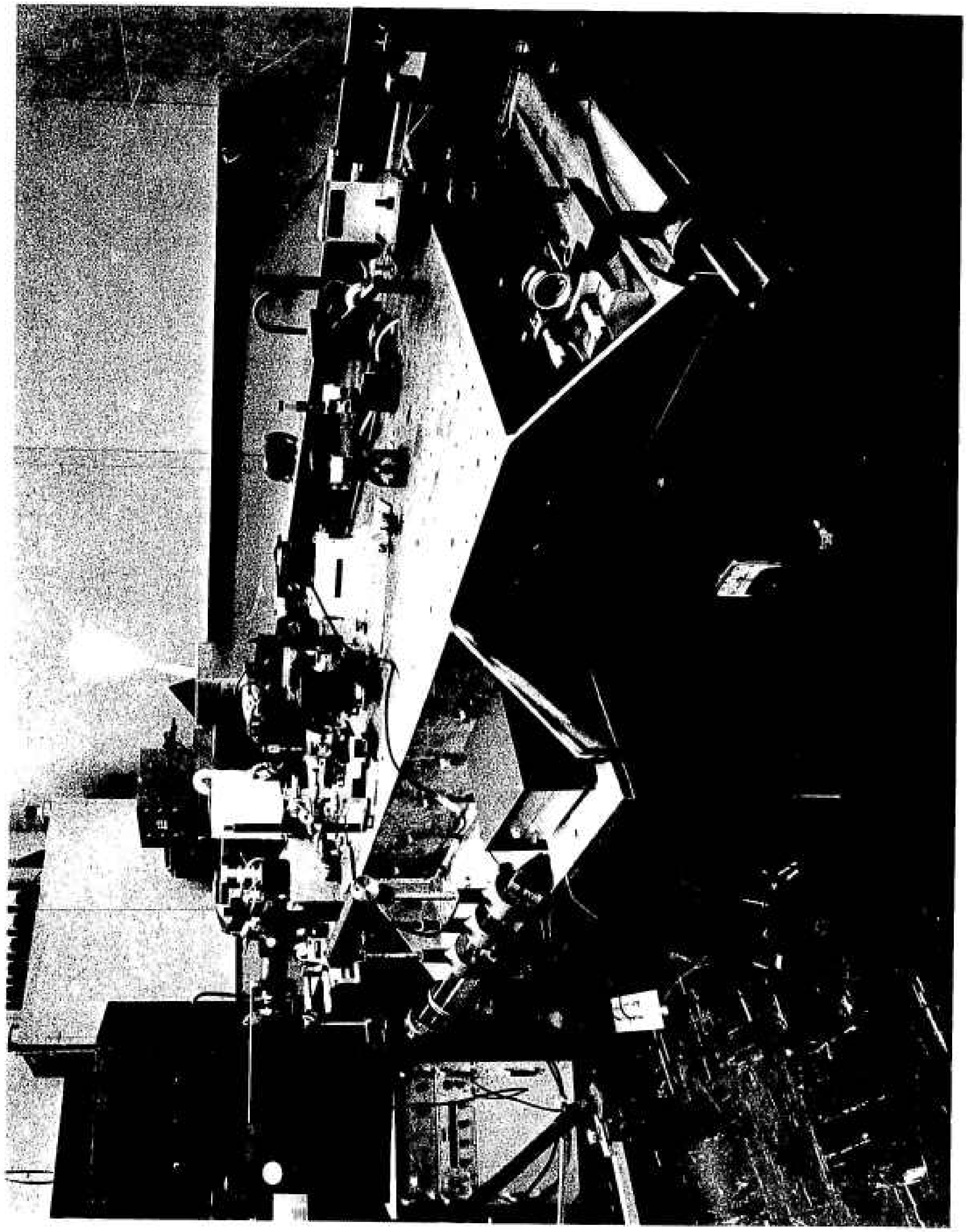


Figure 5. Photograph of Present Layout

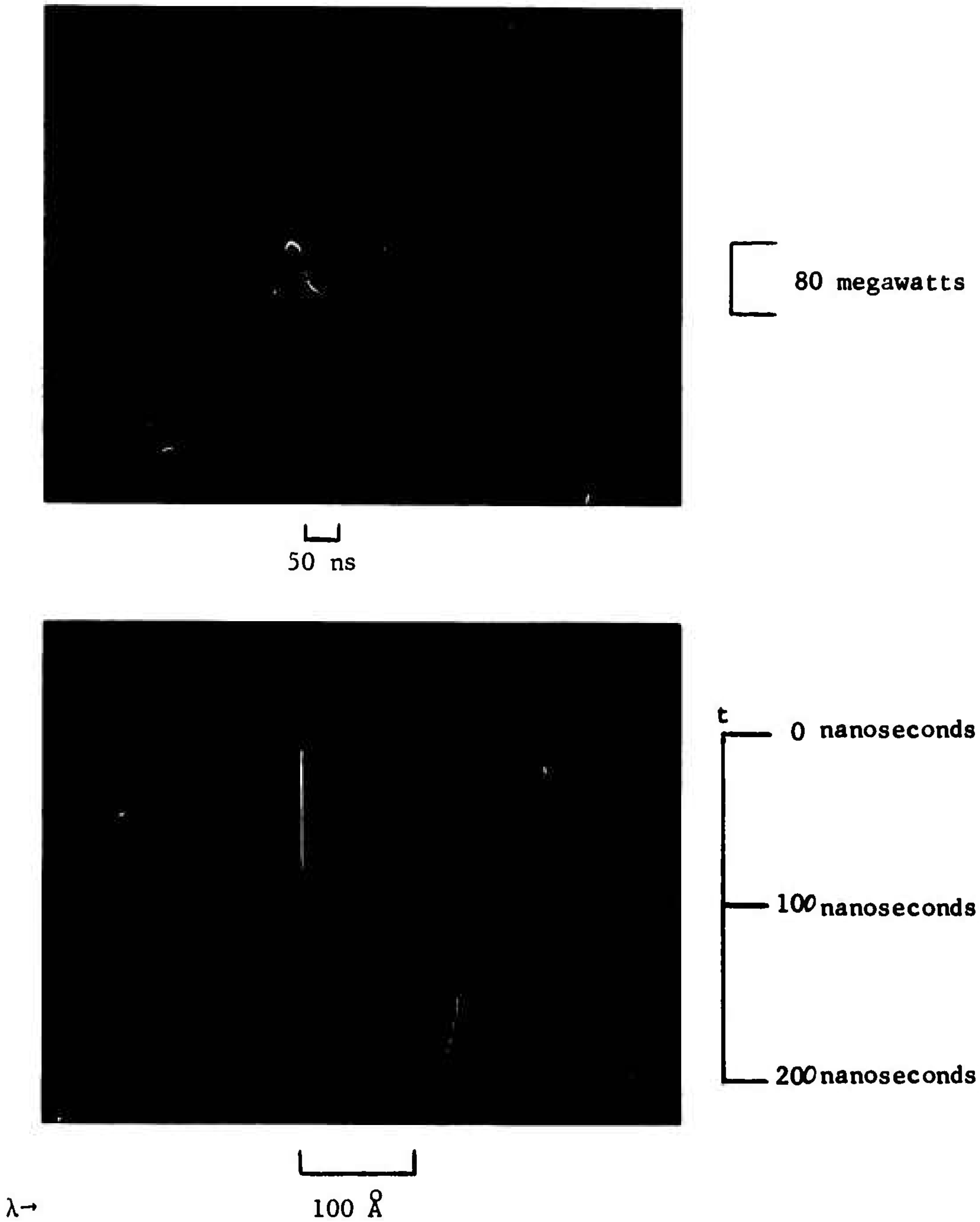


Figure 6. Scope and Streak Photographs of Perturbing Laser

the exhaust end of the dewar. The temperature recorded is thus the highest temperature of any part of the rod surface. It takes about 3 minutes for the rod to come back to thermal equilibrium after each pulse. There is no frosting or detectable distortion due to the windows and seals of the dewar assembly.

Experiments were carried out at liquid nitrogen temperature using the 2% Nd-doped glass rod. The probe pulse was intense enough to expose the film on a 50 nanosecond streak with all the previously mentioned component changes in the system. The Q-switched perturbing laser was operated with a 6 joule output in a 40 nanosecond pulse. A photograph of the entire system being fired is shown in Fig. 7. A difficulty arose in that with this new ratio of beam splitters and increased intensity of the perturbing laser, the additional light overcame the scattered light baffles in the spectrometer and overexposed the center of the streak photograph. A measurement of the attenuation required to eliminate this unwanted light was made and found to be a factor of 50. The degree of depolarization of this Q-switched light is presently being measured. If it is not seriously depolarized it can be filtered out at the streak camera by a Polaroid Corp. type HR infrared polarizing sheet.

4. Densitometer

The calibration procedure mentioned previously[(5)] which involved splitting the image in the rear of image converting camera was not practical to carry out in the confined space available in the rear of the camera. It was found difficult to design an optical system that would split the image and translate it while maintaining the resolution and focal planes of both images on the Polaroid film.

(5)Second Semi-Annual Technical Summary Report, p. 13, 1 August 1966 - 31 January 1967

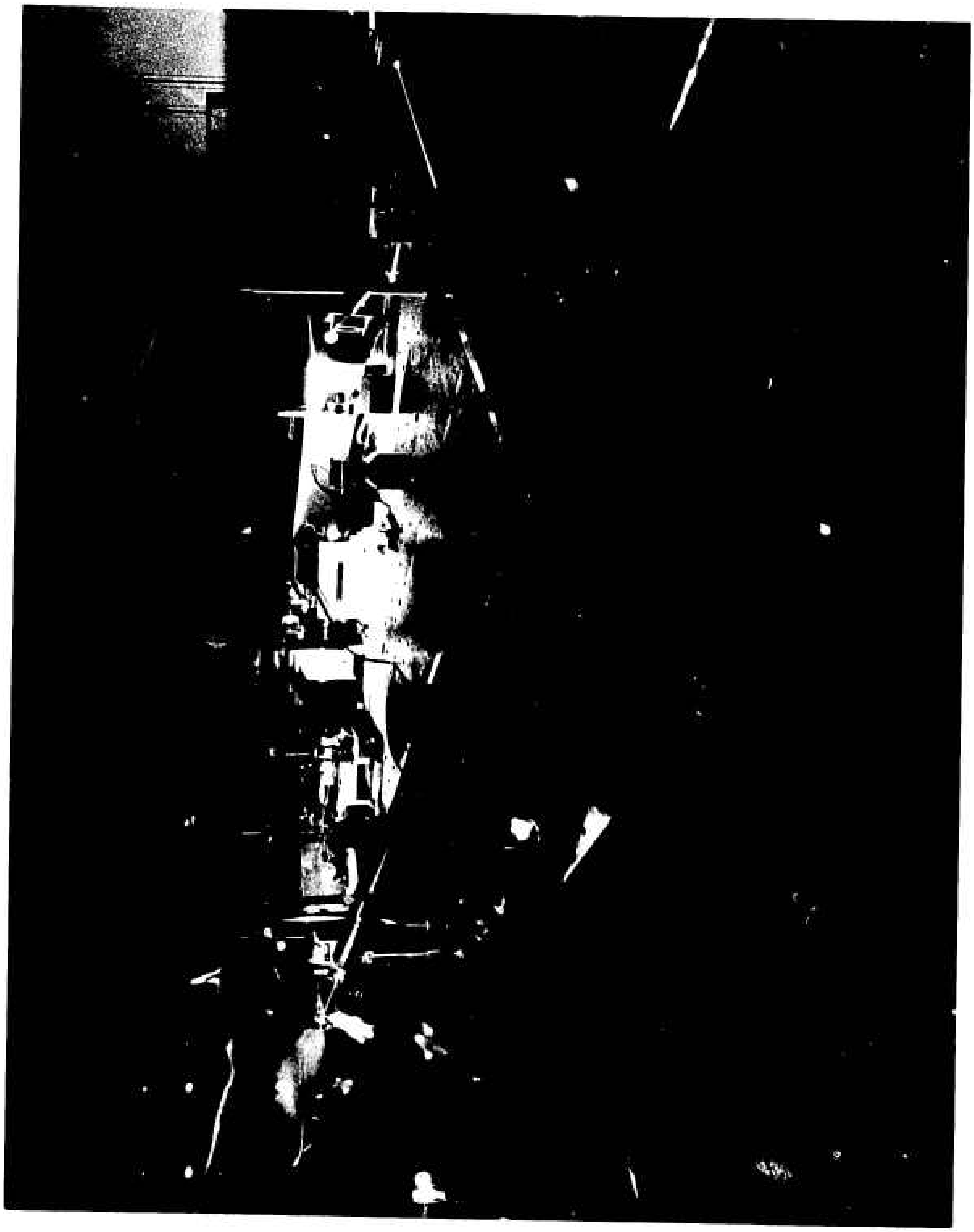


Figure 7. Photograph of Interaction Amplifier Experiment in Operation

A new precise calibration method was developed which was easier to carry out. A holder was made which allowed the insertion of a transmission step-wedge in front of the streak camera at the focal plane of the spectrograph. A diffuser and light source were installed in the spectrograph that back-lighted the step-wedge uniformly. A picture of the step-wedge is then photographed by the streak camera on each streak photograph. The density tracing of the actual step-wedge and the image of it on the Polaroid film are then compared to ascertain the correction factors to be applied to the density tracings of the probe streaks. The dynamic range of the Polaroid film Type 410 (ASA 10,000) is 5 steps of the eight step density wedge which is a 15 dB range. Several typical calibration-streak exposures are shown in Fig. 8.

B. TWO PHASE NATURE OF GLASS

Ceramists in our research center have carried out considerable work on the two phase nature of certain glasses.[6] The compiled data on glasses makes it possible to predict with reasonable accuracy, whether or not a particular glass is a two phase material.

The constituents of commercially available glass laser rods were collected and a survey of these indicated that only the American Optical 0835 glass was a borderline case. All of the other glasses whose constituents are publicly known were considered definitely to be single phase. A study of the 0835 was undertaken. The technique for determining whether a glass is two phase is to either look at electron microscope transmission through a fresh glass splinter or make a platinum and carbon shadow replica which is photographed in the electron transmission mode. A photograph of a two phase glass made by the replica is shown in Fig. 9 at 25,000 magnification.

(6)R.J. Charles and F.E. Wagstaff, "Metastable immiscibility in the B_2O_3-SiO_2 system", J. Amer. Ceramic Soc., vol. 51, pp. 16-20, January 1968

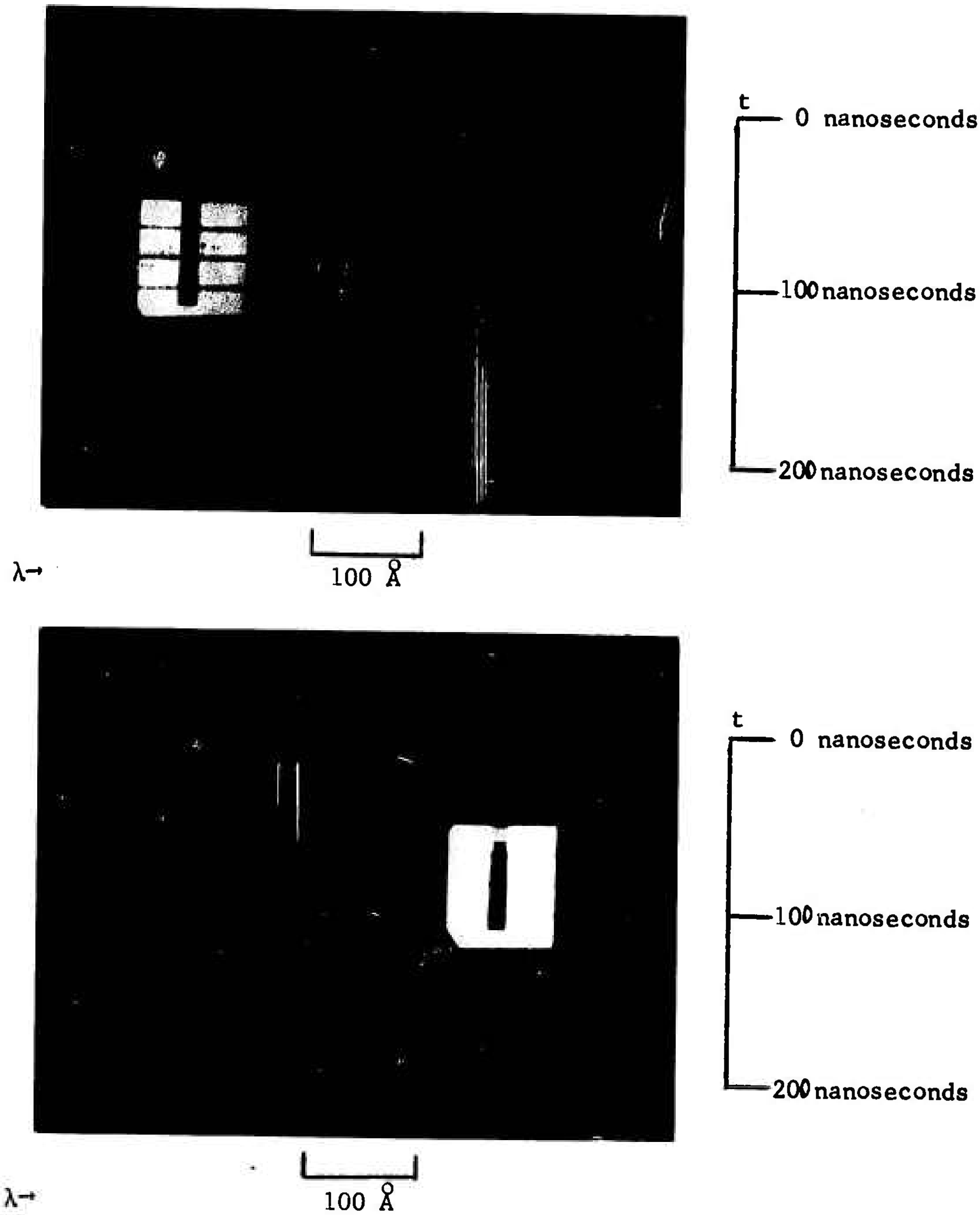


Figure 8. Streak Photographs with Calibration Wedges

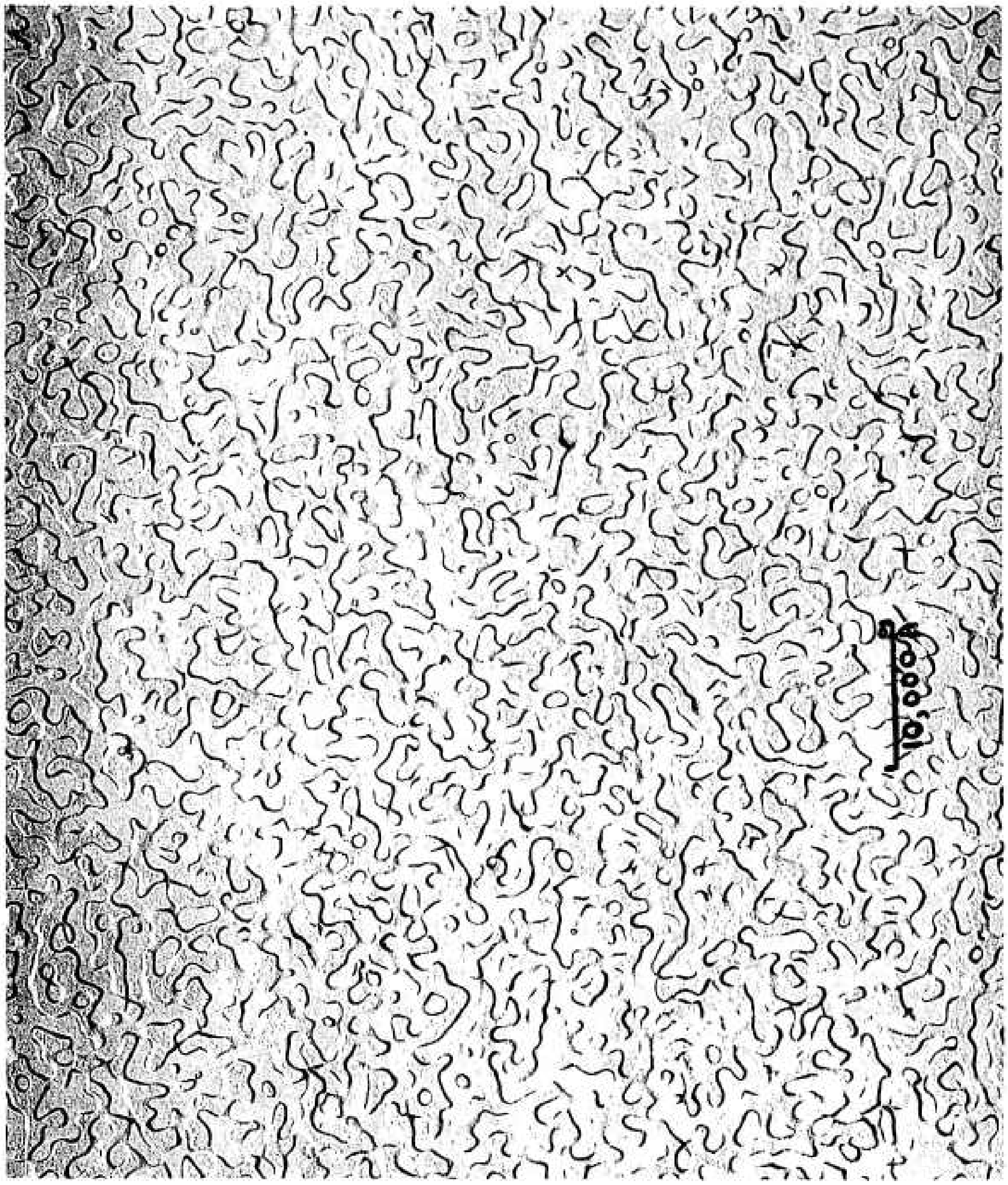


Figure 9. An Electron Microscope Photograph of a Two Phase Glass (10.7% Na_2O, 47.5% B_2O_3, 41.7% SiO_2)

A study of the 0835 laser glass indicated it was single phase. An electron microscope photograph of 0835 glass splinter in the transmission mode is shown in Fig. 10. This scale is 243,000 magnification and no two phase effects are visible. The sharp edge in the photograph is the edge of the splinter.

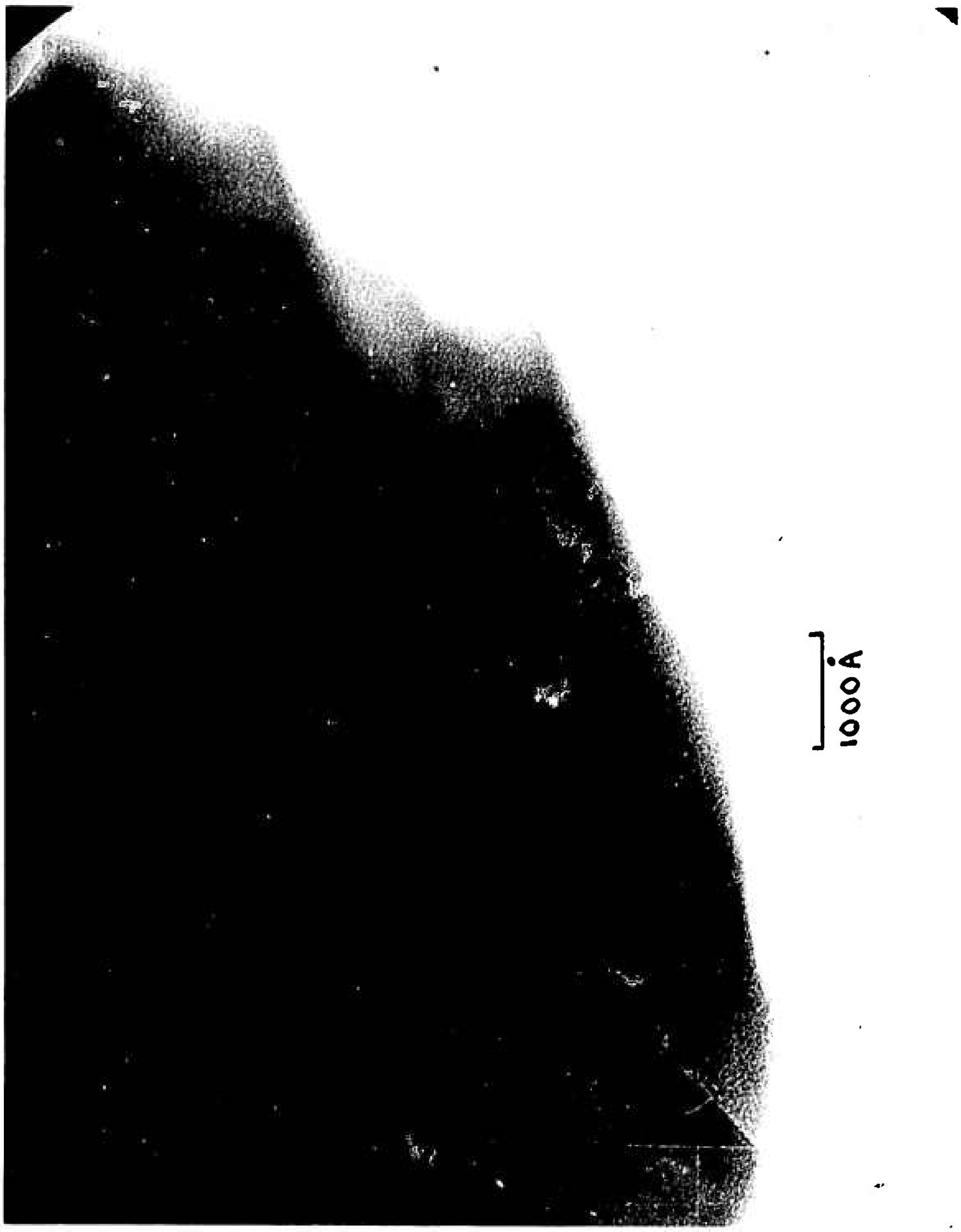


Figure 10. An Electron Microscope Photograph of American Optical 0835 Laser Glass

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13. ABSTRACT

This is a semi-annual report on investigations of cross relaxation between neodymium ions in laser glass. Work performed during the last six months is described.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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